IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Scott et al.

Application No.: 09/904,600

Filed: July 12, 2001

Title: ELECTRODE PROBE COIL FOR MRI

Attorney Docket No.: STFUP076/S00-131

Examiner: Lin, Jeoyuh

Group: 3737

DECLARATION UNDER 37 CFR § 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

We, Greig C. Scott and Garry E. Gold, declare as follows:

1. We are the inventors and Applicants in the above-identified patent application.

2. We are employed as Senior Research Associate at Stanford University (Assignee herein) and Assistant Professor of Radiology at Stanford Medical Center, respectively.

3. The invention as disclosed and claimed has been successfully employed to detect magnetic resonance signals in a human body. Electrodes of a probe function with conducting medium in a region of interest as a coil for detecting magnetic resonance signals.

4. We have demonstrated successful reduction to practice of the invention in our papers titled, "Electrode Probes for Interventional MRI," Proceedings of the International Society for Magnetic Resonance in Medicine, Volume 8 (2000), copy attached hereto and of record in the patent application and our paper titled, "Electrode Probes for Interventional MRI," a poster in 2000 at Denver International Society of Magnetic Resonance in Medicine Conference, copy attached hereto and also of record in the patent application.

As there depicted in Figs. 2(b), a human femoral artery specimen is imaged in the axial plane using magnetic resonance signals detected with a probe in accordance with the invention.

5. While both papers referenced above have five coauthors, the claimed invention was derived solely from us.

6. We further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both (under Section 1001 of Title 18 of the United States Code), and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

April 6 2004
Date

Greig Scott

3/23/04
Date

Garry Gold

Electrode Probes for Interventional MRI

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Introduction

Recent interest in intravascular imaging and interventional MRI has prompted a need for micro-coils that can be inserted in vessels and body cavities [1]. While traditional MRI probes are tuned coils, a recent innovation by Ocali was the idea of the loopless dipole probe - the idea being the field of sensitivity was that of a dipole antenna[2]. However, a more general viewpoint is that any two implanted electrodes simply form a resistor/capacitor and will create a B1 sensitivity pattern determined by current flow in a lossy medium. The flexibility of using multiple electrodes can create targeted patterns of sensitivity. The concept is demonstrated with a parallel wire configuration.

Lossy Dielectrics

Reciprocity predicts that, for any two implanted electrodes, with unit RF current impressed, the electric field creates a current J= (+j)E which in turn creates an RF magnetic field. The components transverse to Bo are the B1 sensitivity.

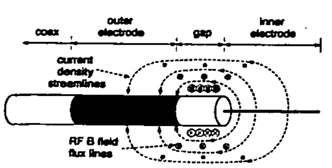

Figure 1: A loopless dipole probe acts as a parallel resistor-capacitor with coaxial electrodes.

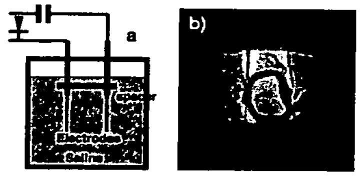

Figure 2: a) Test Phantom and b) Femoral Artery. The wire electrodes are 4cm long with 1cm separation in 0.9% saline. The capacitor (88pF) blocks DC and improves matching.

Radiation fields are exponentially attenuated with parameter and varying with conductivity and permittivity [3]. If = 0.5, = 80 o, then at 64 MHz, = 8.6Np/m, and = 0.43 meters. For a size scale of /10, the field sensitivity pattern is well predicted by a complex laplace equation [4] ignoring radiation. The near field sensitivity of a loopless dipole (fig 1) behaves as 2 coaxial electrodes forming a parallel resistor-capacitor in tissue. RF current density images at 2T on electrode phantoms also yield similar near field behavior[5,6].

Results

Figure 2a shows a diagram of our electrode probe saline phantom. The probe impedance, Z=34+j23 , is partly tuned by a DC blocking capacitor and PIN diode network. Figure 2b shows a human femoral artery specimen imaged in the axial plane. Excellent detail from the intima and adventitia of the artery is seen.

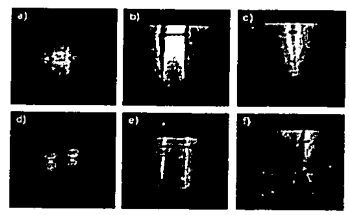

Figure 3: Phantom Images. a-c) are axial, coronal, and sagittal images with the probe wires places parallel to Bo. d-f) are axial, coronal, and sagittal images with the probe wires perpendicular to Bo. (Spin Echo, TR:800, TE:14, NEX:1, 256x256, FOV:12cm).

Spin echo images with a 12cm FOV were acquired for axial, sagittal, and coronal planes with the electrode pair in a plane parallel to and then perpendicular to Bo. Figure 3a-c shows these views for the electrodes in a plane parallel to Bo and d-f for the electrodes in a plane orthogonal to Bo. The electrode probe shows much greater sensitivity when coplanar with Bo since the feed-wire and tissue current path form a loop giving maximum transverse B1. Figure 4 shows an example image of the glenoid labrum using the electrode probe coil. Figure 5 shows a high-resolution image of the labrum.

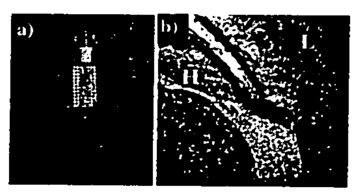

Figure 4: Images from a cadaver shoulder. a) Electrode probe. b) Image showing detail in the glenoid labrum using the electrode probe coil. The humeral head (H) is adjacent to an electrode wire next to the glenoid labrum (L). TR: 800, TE: 14, NEX:1, 256x256, FOV: 8cm.

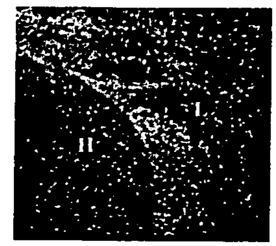

Figure 5: High resolution image of humeral head (H) and the glenoid labrum (L) using the electrode probe coil. TR: 800, TE: 14, NEX:1, 256x256, FOV: 8cm.

Conclusions

These results demonstrate that an implanted electrode pair can be used for MRI signal reception. High sensitivity occurs in regions where current density flow can create transverse B1 fields. By changing the electrode and feed-wire geometry, we can sculpt the sensitive volume. RF ablation electrodes could also form suitable interventional MRI probes. This technique may prove useful in high-resolution imaging of joints in conjunction with MR arthorgraphy, characterization of atherosclerotic plaque, or imaging of neoplasms.

References

[1] Hurst, GC et al, MRM, 24:343, 1992.
[2] Ocali O, Atalar E, MRM, 37:112, 1997.
[3] Paris D, Hurd F, Basic Electro. Theory, 1969.
[4] Konrad A, J Applied Phys, 53:8408, 1982.
[5] Scott et al, MRM, 33:355, 1995.
[6] Scott et al, IEEE TMI, 14:515, 1995.

Electrode Probes for Interventional MRI

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Introduction Recent interest in intravascular imaging and interventional MRI has prompted a need for microcoils that can be inserted in vessels and body cavities [1]. While traditional MRI probes are tuned coils, a recent innovation by Ocali was the idea of the loopless dipole coil - the idea being the field of sensitivity was that of a dipole antenna[2]. However, a more general viewpoint is that any two implanted electrodes simply form a resistor and will create a B1 sensitivity pattern determined by current flow in a lossy medium. The flexibility of using multiple electrodes can create targeted patterns of sensitivity. The concept is demonstrated with a parallel wire configuration.

Sensitivity in Lossy Dielectric The qualitative operation of the loopless dipole used its antenna radiation pattern which fell as $1/r$. However, in lossy media with conductivity σ, and permittivity ϵ, the wave propagation constant $(\alpha + j\beta)^2 = j\omega\mu_o(\sigma + j\omega\epsilon)$ causes an additional exponential attenuation α with wave number β also dependent on conductivity [3]. If $\sigma = 0.5$, $\epsilon = 80\epsilon_o$, then at 64 MHz, $\alpha = 8.6$Np/m, $\beta = 14.7$rad/m, giving $\lambda = 0.43$ meters. In free space, radiation terms do not exceed quasistatic fields until $r > \lambda/6$ but in lossy media quasistatic fields still dominate. Since the size scale is still only $\lambda/10$, the field sensitivity pattern is equally well predicted by a complex laplace equation [4]. This has been verified in RF current density imaging tests performed at 2 Tesla on electrode phantoms [5,6]. Reciprocity predicts that, for any two implanted electrodes, with unit RF current impressed, the electric field creates a current $J = (\sigma + j\omega\epsilon)E$ which in turn creates an RF magnetic field. The components transverse to B_o are the B_1 sensitivity. From this viewpoint, the "dipole" is just two coaxial electrodes (fig 1) forming a parallel resistor-capacitor in tissue.

Experimental Results We placed two parallel wire electrodes, 4cm long, separated by 1 cm, in a 0.9% normal saline solution. Without matching, $Z = 34 + j23\Omega$. The matching network just tuned out the reactive component with a series 88 pF capacitor and shunt PIN diode. Figure 2a shows a diagram of our electrode probe, while Fig. 2b shows a human femoral artery specimen imaged in the axial plane. Excellent detail is seen. Spin echo images (TR:800,TE:14,NEX:1,256^2) with a 12cm FOV were acquired for axial, sagittal, and coronal planes with the electrode pair in a plane parallel to and then perpendicular to B_o. Figure 3a-c shows these views for the electrodes in a plane parallel to B_o and d-f for the electrodes in a plane perpendicular to B_o. The electrode probe, shows much greater sensitivity when coplanar with B_o since the current path in tissue and feedwires forms a loop giving maximum transverse B_1.

Discussion & Conclusions These results demonstrate that an implanted electrode pair can be used for MRI signal reception, creating maximum sensitivity in regions which support current density flow parallel to B_o. The most interesting aspect of this approach, is that by changing the electrode geometry, we can sculpt the sensitive volume. This coil may prove useful in high-resolution imaging of joints in conjunction of MR arthorgraphy, characterization of atherosclerotic plaque, or imaging of neoplasms.

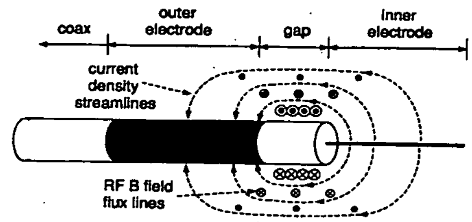

Figure 1: Coaxial Electrode Physics

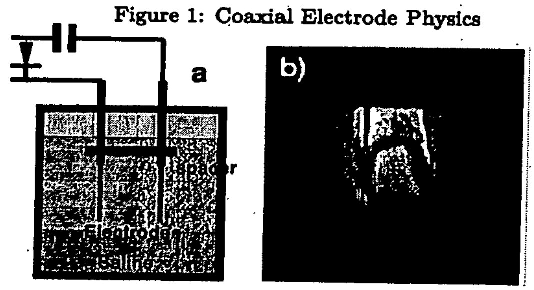

Figure 2: Test Phantom and Femoral Artery

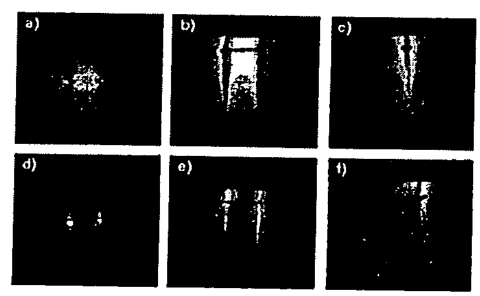

Figure 3: Phantom Images

References

[1] Hurst, GC et al, *MRM*, 24:343, 1992.
[2] Ocali O, Atalar E, *MRM*, 37:112, 1997.
[3] Paris D, Hurd F, *Basic Electromagn. Theory*,1969.
[4] Konrad A, *J Applied Phys*, 53:8408, 1982.
[5] Scott et al, *MRM*, 33:355, 1995.
[6] Scott et al, *IEEE TMI*, 14:515, 1995.